SECTION 2
STANDARD AND MEASUREMENT PROCEDURES

INTRODUCTION

Whenever the emission spectra of microwave ovens are measured, individuals reviewing the results invariably want to compare the data against the requirements set out in national and international standards. Those standards and associated measurement procedures reasonably serve as a starting point for evaluating techniques for performing measurements of microwave ovens.

National spectrum management authorities establish emission limits for radio-based technologies, such as ISM, to protect radio services. Therefore, the selection of an emission limit should ultimately be linked to the kind of protection desired and the nature of radio devices being protected. The standards compliance testing procedures and measurement results should be reasonably applicable for evaluating compatibility in situations common to a particular radio environment. As radio technologies evolve, spectrum regulatory authorities must update their standards to ensure that limits continue to be appropriate and adequate, without being unnecessarily restrictive. However, an emission limit is defined not only by the limit value but by the method of measurement. Therefore, any limit must include an associated measurement procedure. The method of measurement must enable the recording of emitter levels in a manner that is meaningful in the context of radio services to be protected. In fact, the terms in which a limit is stated (peak or average detector and measurement bandwidth) must be settled before considering a limit value. Furthermore, the measurement procedure needs to be sufficiently detailed to ensure consistent application and repeatable results. Procedural variations alter the result of any measurement, and thus the record of emission levels and compliance with emission limits. In the case of microwave ovens, the method of measurement may need to specify the test instrumentation, and parameters related to oven operation.

When designing microwave oven equipment, manufacturers face a variety of requirements from national and international regulatory and standards organizations. For ovens operated within U.S. borders, the FCC bears responsibility for regulating emissions from privately owned microwave ovens. The FCC regulates the operation of microwave ovens as ISM equipment via Part 18 of its Rules.[6/] Associated measurement procedures are included in a separate document, FCC/OST MP-5 (hereinafter referred to as MP-5).[7/] Ovens owned and operated by agencies of the Federal Government are regulated by NTIA. However, maintaining separate emission standards for private sector and federally owned ovens is not practical, since ISM equipment operated by the private sector far outnumber those of the

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6/ *Title 47, Code of Federal Regulations*, Part 18, October 1992, pp. 595-602.

7/ *FCC/OST MP-5 (1986)*, "FCC Methods of Measurements of Radio Noise Emissions From Industrial, Scientific, and Medical Equipment," Federal Communications Commission, Office of Science and Technology, February 1986.

Federal Government. Therefore, NTIA has chosen to draw its standard from the FCC standard. Federal Government standards are stated in Chapter 7 of the Manual of Regulations and Procedures for Federal Radio Frequency Management.[8]

The situation with respect to international standards is less clear. The ITU does not have standards or regulations governing the level of emissions of ISM equipment. Task Group 1/2 of the ITU Radiocommunication Sector recently completed a recommendation on ISM standards. The task group recommends that administrations consider using the CISPR standard for ISM. CISPR sets standards for ISM devices within CISPR Publication 11 (hereinafter referred to as CISPR 11).[9] However, with the exception of a limit for the range 11.7-12.7 GHz, CISPR 11 has no standards for ISM that apply to radiated emissions above 1 GHz. CISPR Subcommittee B is currently developing limits covering 1-18 GHz. Many national administrations have their own standard, and microwave oven manufacturers must identify and meet these national requirements, creating a difficult task for international marketing. If the members of the European Economic Community (EEC) eliminate their individual standards in favor of a unified standard, the variety of requirements will be cut significantly. Decision-makers within the European standards process have determined that the EEC will follow CISPR standards where such standards exist. Due to the lack of CISPR standards above 1 GHz, the future requirements remain unclear. Therefore, emission limits and related compliance measurement procedures for microwave ovens continue to vary from country to country.

The following discussion describes the national and international standards that apply to microwave ovens and considers the associated methods of measurement.

FCC STANDARD AND MEASUREMENT PROCEDURES

Via Part 18, the FCC applies a field strength limit of 25 μV/m at 300 meters for ISM equipment that operate in the 2450 MHz ± 50 band if the equipment generates less than 500 Watts. For equipment generating 500 Watts or more, as most microwave ovens do, the Part 18 field strength limit (in μV/m) at 300 meters is:

$$25\sqrt{power/500}$$

8/ *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications and Information Administration, Department of Commerce, May 1992 Edition (Revisions through May 1993), Paragraph 7.10.1, pp. 7-7 through 7-8.

9/ *CISPR Publication 11*, "Limits and Methods of Measurement of Electromagnetic Disturbance Characteristics of Industrial, Scientific and Medical (ISM) Radio Frequency Equipment", Second Edition, International Special Committee on Radio Interference, International Electrotechnical Committee, Geneva, Switzerland, 1990.

However, the emissions from higher-powered devices may not exceed 10 μV/m at 1600 meters.[10] Even though these limits apply to equipment with operating frequencies in an ISM designated band, they apply only to emissions that occur outside the ISM bands. Within the ISM bands themselves, no limit applies.

Part 18 criteria requires that microwave oven emissions, outside the ISM bands, must not exceed the specified amplitude at a distance of 300 meters from the oven. However, within the Part 18 text, the FCC does not specify test procedures, such as the type of detection, the measurement bandwidth, the length of the test, or the test load, to be used in assessing oven emissions. Instead, Part 18 § 18.311 references MP-5 as its guidance for performing measurements of ISM. While noting that the use of those procedures is not mandated, Part 18 encourages manufacturers to use the MP-5 procedures as that which the FCC uses.

MP-5 § 2.2 specifies measuring ISM equipment with a field intensity meter (in MP-5, referred to as a radio noise meter) that conforms with the American National Standard Specifications for Electromagnetic Interference and Field Strength Instrumentation 10 kHz to 1 GHz, ANSI C63.2-1980.[11] It permits measurements to be made at a distance closer than that specified for the limit, such as 3 meters, provided the results are extrapolated to 300 meters. The procedure stipulates that the measurement bandwidth be 1 MHz, and that the detector be linear and set to read average levels. However, field intensity meters for measurements above 1 GHz are very expensive. Today, when spectrum analyzers are often used instead of such meters, particularly above 1 GHz, a procedure specific to those spectrum analyzers is needed. Recognizing that field intensity meters may not be readily available or are prohibitively expensive, the FCC allows (see MP-5 § 2.2) that "[a]lternatively, a spectrum analyzer may be used, provided the results obtained can be accurately reproduced with a suitable radio noise meter. . . ." The FCC has verbally conveyed to some test labs a set of test procedures facilitating the use of a spectrum analyzer. These procedures, though not altering the stated limit, do alter the process used by those test facilities to determine oven compliance. Of the two major U.S. manufacturers of microwave ovens, one uses this procedure while the other uses the field intensity meter. The unofficial spectrum analyzer procedures are summarized in Appendix A. Furthermore, the FCC permits other instruments

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10/ Part 18 of the FCC Rules does not specify whether the field strength limit values are peak or average. However, measurement procedures recommended by the FCC indicate the values represent a type of average.

11/ ANSI C63.2-1980, *American National Standard for Instrumentation - Electromagnetic Noise and Field Strength 10 kHz to 1 GHz - Specification*, American National Standards Institute, The Institute of Electrical and Electronics Engineers, Inc., New York, NY, 1980. This document was updated in 1987 to cover up to 40 GHz; however, no specifications are provided for the use of spectrum analyzers. Spectrum analyzers specifications are said to be under consideration. See ANSI C63.2-1987, *American National Standard for Instrumentation - Electromagnetic Noise and Field Strength 10 kHz to 40 GHz - Specification*, American National Standards Institute, The Institute of Electrical and Electronics Engineers, Inc., New York, NY, February 1987.

to be used for "certain restricted and specialized measurements when data so measured are correlatable to that achieved by C63.2 instrumentation" but provides no guidance as to what cases this applies. The official field intensity meter procedure and the unofficial spectrum analyzer procedure are clouded by the statement in MP-5 § 2.2 that, "No specific standard will be required for instrumentation used to perform measurements above 1 GHz," and by the fact that the version of the ANSI specification referred to by MP-5 covers field-strength instrumentation only from 10 kHz to 1 GHz. Procedures for microwave oven measurements for ranges above 1 GHz are probably the most important. The updated ANSI C63.2-1987 still leaves a void, stating that "[a] separate document covering spectrum analyzers for use from 20 Hz to 40 GHz is in preparation. . . ."

Regardless of the instrumentation, MP-5 § 2.2.2 specifies that the detector function shall be set to average, and shall be linear. Both of these detector characteristics can create difficulties depending on the emission characteristics of the ISM equipment and the receivers that the standard intends to protect.

"Average" is a mathematically defined quantity, and many different averaging functions exist. These include, but are not limited to, linear average, log average, and root-mean-square (RMS) average. Because each type of average provides different measurement results, the specific averaging function must be defined in a measurement procedure.

Linear average power of a pulsed emitter, for example, is the total energy emitted by the device during a pulse repetition interval and divided by that interval. Equivalently, average power may be obtained by measuring the peak power and multiplying by the duty cycle of the device, assuming that pulse time waveforms are roughly rectangular. Strictly defined, the measured peak power should include all energy emitted by the device. As a measurement bandwidth sufficiently wide to include most or all energy in the spectrum might be unobtainable, the total power value could also be obtained by measuring power in a narrower bandwidth and taking a series of such measurements across the emission spectrum in such a way as to integrate most or all power in the emitted spectrum within that series of measured points.

Another type of averaging, often referred to as "video averaging," is included in the unofficial FCC procedures. It is performed by using a relatively wide IF bandwidth (typically about 1 MHz) and a narrow post-detector video bandwidth (as narrow as a few hertz).[12/] The idea behind this technique is to utilize an IF bandwidth and an envelope detector that are sufficiently wideband to follow fluctuations of the signal in the pre-detector stages, and then to obtain an average value by smoothing the signal with a narrow post-detection low-pass filter (the video bandwidth). A linear amplitude display is required on the spectrum analyzer

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12/ "Spectrum Analysis," Application Note 150, pp. 16-17, Hewlett-Packard Company, November 1989; "Automatic CISPR EMI Testing," Application Note 331-1, pp. 26-27, Hewlett-Packard Company, 1986; "Performing CISPR-Required Average Measurements Using a Spectrum Analyzer," Hewlett-Packard Company; S. Linkwitz, "Measurement of Narrowband and Broadband Emissions Using Peak and Average Detection," IEEE/EMC Symposium 1987.

for this type of measurement. In effect, this average suppresses the broadband content of the measured signal, allowing measurement of its narrowband, continuous-wave-like (CW) component, if any.

Video averaging works well as long as the dynamic range of the signal being measured can be accommodated within the dynamic range of the linear amplifier in the measurement system. However, if the dynamic range of the measured signal exceeds the dynamic range of the linear amplifier, the video average will no longer reflect the true average of the signal. In cases where the dynamic range of the linear amplifier is sufficient, the video average is still only a single data point, which does not indicate the RMS average, the peak value of the signal, or the percentage of time over which the signal exceeds any given threshold, including the average value itself.

For spectrum analyzers, the FCC has unofficially recommended a 1 MHz intermediate frequency (IF - often referred to as the resolution bandwidth) measurement bandwidth coupled with a narrow (3 Hz) post-detector video bandwidth. The choice of 3 Hz video bandwidth eliminates from observation impulsive, low duty cycle components of an oven's emissions. The only emissions that will be observed under these procedures will be high duty cycle, almost CW components of an oven signal. These procedures may be useful for making measurements of line structure in the spectra of a repetitive and structured pulsed wave form; however, microwave ovens do not exhibit this line structure characteristic because of the rapidly shifting frequency.

The unofficial FCC measurement procedures may indicate emission levels which are tens of decibels lower than would be indicated by wide bandwidth, peak-detected measurements. Figure 2-1 shows three time waveforms taken at the same frequency with a wide IF bandwidth (3 MHz) and video bandwidths of 1 MHz, 10 Hz, and 3 Hz. The data shown in Figure 2-1 were acquired at a frequency of 2365 MHz. This frequency was selected because the oven tested (Oven #1)[13/] showed, during emission spectrum measurements, a high emission level at that frequency. Measured oven emissions decrease with decreasing video bandwidth, and drop off most markedly at bandwidths less than about 1 kHz. When a video bandwidth of 3 Hz is reached, the variations in the oven emissions are no longer observable. The measured values give no indication of the peak amplitudes that occur, nor do they indicate the percentage of time that the signal exceeds any given threshold. Thus, the measurement procedure itself eliminates the record of the existing signal, potentially crucial for the interference prediction on which a limit might be based, and certainly important to standards compliance testing. The dynamic range of the signals measured in this case was such that linear amplification could not be used to get an accurate measurement, a problem cited above for the video averaging technique. Because ITS did not have a field intensity meter for making measurements above 1 GHz, they could not determine whether the video bandwidth procedure meets the FCC's own requirement that it reproduce accurately measurements performed with a field intensity meter.

13/ The microwave ovens tested and the associated numbering scheme is described in detail in Section 3.

In light of increasing use of wideband receivers, the value of protecting radio systems by basing limits on average values which generally reflect narrow bandwidth, high duty-cycle components is unclear (whether using a field intensity meter or a spectrum analyzer). Such techniques will produce results that do not reflect peaks and tend to lessen the differences between emission characteristics of pulsed emitters. The use of linear detectors also may not be adequate to record the large range of microwave ovens emission levels. The FCC documents referenced herein do not indicate the rationale behind the selection of their official or unofficial procedures. However, Part 18 was developed in the late 1970s, and most radio receivers designed in that period would have used analogue techniques with relatively narrow bandwidths. Average emission levels and averaging measurement techniques would be appropriate to protect such systems.

The use of a field intensity meter to accurately record the maximum emissions outside the ISM band is further complicated by the difficulty of identifying at which frequency the device should be set. The FCC, as a matter of procedure, measures the field strength at the ISM band edge at 2400 MHz, where the highest emissions outside the band might be expected, assuming that field strength decreases with frequency separation from the primary operating frequency. However, higher levels may be emitted at lower frequencies. Some ovens have a characteristic secondary peak somewhere between 2300 and 2400 MHz.

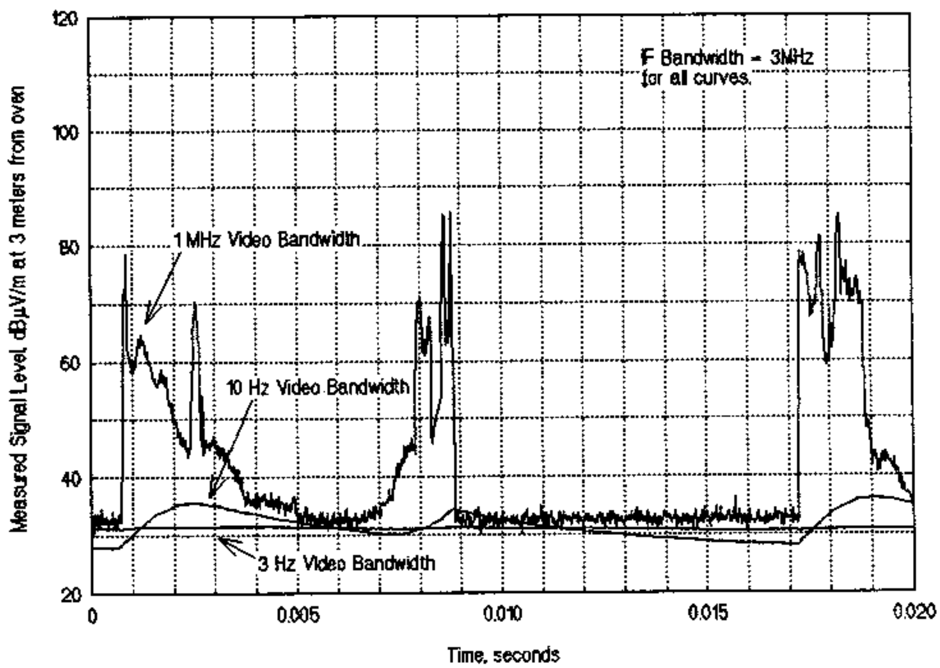

Figure 2-1. Emissions in decreasing video bandwidth.

CISPR STANDARD AND MEASUREMENT PROCEDURES

CISPR limits and methods of measurement for ISM equipment, including microwave ovens, are stated in CISPR 11. As noted above, CISPR has not yet specified limits above 1 GHz with the exception of the 11.7-12.7 GHz band. In that range, Paragraph 5.2.3 specifies a limit of 57 dBpW effective radiated power (referred to a half-wave dipole). CISPR Publication 16 (hereinafter referred to as CISPR 16), a guide for performing ISM measurements, gives information on making measurements up to 1 GHz and does not define detection functions above that frequency.[14/] CISPR 11 § 9 provides some indication as to possible procedures for measurements above 1 GHz. Manufacturers must currently assume that these procedures apply only to oven tests in the 11.7-12.7 GHz range. Yet, without more detail in the measurement technique, variations in application exist and will continue to exist between administrations. CISPR Subcommittee B is currently developing limits to apply above 1 GHz; however, the subcommittee rejected its most recent proposal, CISPR/B(Secretariat)84, because participants could not yet agree on the limit values.[15/] That proposal, although formally rejected, represents the closest thing to an agreement reached so far. Application of a standard based on CISPR/B(Secretariat)84 would have been difficult had agreement been reached. The proposal recommended use of a peak detector, a method not defined in CISPR 16.

The CISPR 16 guidelines specify the use of a quasi-peak detector (including charging, discharging, and display time constants for the detector), as well as the measurement bandwidths to be used with the detector in four frequency bands between 0.01 GHz and 1 GHz. The 6 dB bandwidths specified in CISPR Publication 16 are listed in TABLE 2-1.

TABLE 2-1
CISPR PUBLICATION 16 MEASUREMENT BANDWIDTHS

Frequencies (MHz)	6 dB IF Filter Bandwidth (kHz)
0.01-0.15	0.2
0.15-30.0	9
30-300	120
300-1000	120

14/ *CISPR Publication 16*, "Specification for Radio Interference Measuring Apparatus and Measurement Methods," Second Edition, International Special Committee on Radio Interference, International Electrotechnical Committee, Geneva, Switzerland, 1987.

15/ CISPR/B(Secretariat)84, "Limits and Methods of Measurement for Electromagnetic Radiation in the Frequency Band 1 to 18 GHz," International Special Committee on Radio Interference, International Electrotechnical Committee, Geneva, Switzerland, May 1992.

The quasi-peak bandwidths and detector response specified by CISPR 16, if applied above 1 GHz, will provide measurements results that, like those under the video averaging tests, tend to discriminate against broadband emissions. If a device under test emits high duty cycle signals (i.e., CW or slowly varying spectral components), then the quasi-peak detector is well-suited to determining the characteristics of those emissions. If an emission is strongly impulsive, the response of the quasi-peak detector to such emissions is reduced at a rate that is roughly proportional to the decrease in the emitter's duty cycle.

CONSIDERATIONS IN SELECTING A MEASUREMENT METHOD

In selecting a measurement method on which a standard can be based, regulatory authorities must consider the radio systems to be protected. Where receivers are susceptible to narrowband components in an emitted signal, a quasi-peak detector response or some other type of average may be desirable. Use of quasi-peak detection is justifiable for interference measurements below 1 GHz, where potential incompatibility between devices often results from the existence of high duty-cycle components. It is also justifiable where the emitter characteristically emits high duty-cycle signals. However, above 1 GHz, receivers often utilize receiver bandwidths of 1 MHz or more. Receivers using such wide bandwidths may be more susceptible to interference from impulsive emissions. If the purpose of measurement procedures is to realistically assess this potential or to measure standards compliance for a limit based on this potential, then such procedures should include detection techniques more responsive to impulsive emissions than quasi-peak detection.

For interference assessments above 1 GHz, and especially for wide bandwidth receivers above that frequency, the use of positive peak detection and wider measurement bandwidths may provide a better indication of the potential for interference. Positive peak detection incorporates a peak-hold latch which retains the highest value sampled from an envelope detector in a specified period.[16/] This approach allows the recording of the emission spectrum over whatever range is necessary, and the frequencies and amplitude of the highest emissions outside the microwave oven band can then be determined. However, peak envelope levels reflect a worst case which can mislead, especially when measuring pulsed emitters that shift in frequency. Emissions at the peak levels may seldom occur. Therefore, some sort of time-oriented measurement is also important. Centering on frequencies of high emissions, time waveforms can be measured, and, using computer generated output, amplitude probability distributions can be produced. These outputs provide data with respect to other aspects of the potential interference problem, specifically the amount of time that receiver threshold levels may be exceeded. Further manipulation of the data can provide pulse-width statistics, or, inversely, clear interval statistics. These statistics,

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16/ Positive peak detection should not be confused with the maximum-hold function, in which the maximum value obtained in each display bin over successive sweeps is retained. Positive peak is a detector function, while maximum-hold refers to a display function. A maximum hold display can be used to portray maximum values for any detector over a measured period, for example, the maximum of an RMS average.

though difficult to incorporate in a standard, can provide information useful to spectrum system planners in determining the compatibility of microwave ovens with planned uses.

Should further research reveal that there are a variety of receiver types that must be considered in emission standards for microwave ovens, then measurements of both average and peak signals and measurements in a variety of bandwidths may be required. If a decibel relationship can be determined between emissions levels recorded in different measurement bandwidths, then measurements could be made in one bandwidth and the results converted to other bandwidths. This approach assumes that, though oven characteristics differ, a reasonably similar wide-to-narrow bandwidth relationship exists between all ovens; and at all frequencies.

SUMMARY

In light of the evolving radiocommunications environment, the FCC needs to review its method of measurement and consequently the related limit value applying to microwave ovens and revise Part 18 as necessary. Satisfactory limits can be set only after having established the general characteristics of the radio uses to be protected and devising the measurement methods to reflect their requirements. The growing demand for systems incorporating wideband digital techniques, places in question whether the current measurement techniques are appropriate for protecting radio systems in the future. Considering that digital technologies above 1 GHz, often use bandwidths of 1 MHz or more and never use bandwidths as narrow as 3 Hz, measurements employing such averaging techniques seem inappropriate. The FCC should not rely on evidence of interference to initiate such a review, but must recognize the growing demand for spectrum and the changing nature of the predominant radio systems if the measurement procedure is to continue to be appropriate.[17/]

If the FCC is to continue authorizing the use of spectrum analyzers for Part 18 compliance testing above 1 GHz, it needs to formalize its procedures for those measurements. The allowance within MP-5 that no specific standard for instrumentation applies above 1 GHz and the acceptance by the FCC of a variety of measurement approaches without verifying the consistency of results nullifies the limit's value. Cost and availability of field intensity meters make use of the MP-5 procedures difficult. Nevertheless, neither the field intensity meter nor the spectrum analyzer video averaging approaches are probably adequate to conduct tests of microwave ovens for the purpose of evaluating the potential for interference to wideband systems.

Positive peak detection in a wide measurement bandwidth is desired if the extended spectral characteristics of an impulsive emitter are to be measured, or if interference is expected to result from broadband emissions. Quasi-peak detection or other averaging

17/ NTIA has in no way attempted here to evaluate the effectiveness of the Part 18 standard to date. In fact, the limits above 1 GHz based on a narrowband averaging technique cannot be meaningfully assessed with respect to protection of digital systems.

techniques are desirable if the characteristics of a high duty-cycle and narrowband signal are to be measured. Microwave ovens are impulsive, broadband emitters, and it is therefore possible that interference due to oven operation, if it should occur, will be due to broadband emissions. If this is the case, then above 1 GHz peak detection in a wide measurement bandwidth will be a more effective method of measurement than an average or quasi-peak based procedure for assessing the interference potential from microwave ovens. The spectrum analyzer video averaging approach recommended by the FCC makes it particularly difficult to discriminate between different broadband emissions and shows little differences between ovens. Peak based measurements of microwave ovens show significant peak power levels and large variations from one oven to another. It is possible that both types of measurements (narrowband/averaged and wideband/peak) should be performed on devices, and that the appropriate set of test results be applied in assessments of interference potential.[18/] This could be done on the basis of the characteristics of receivers potentially operating in the microwave oven environment.

18/ Wideband measurements employing a peak detector will probably require log amplification due to the range of the emission levels produced by a microwave oven.